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Performance comparison for site-specific heat output prediction of solar collectors based on a modified collector efficiency equation model

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Abstract

This study compares the performance of estimation methods for site-specific solar collector yield using two simplified collector efficiency equations-based models for training and testing of the model. Two different collector efficiency equations are used for comparative evaluation: One employs a first order collector efficiency equation defined in terms of collector inlet temperature, solar irradiance, and outdoor temperature, termed first-order equation model with constant T_{ci}. The other equation model is a modified collector efficiency equation expressed with the terms of heating load, solar irradiance, and outdoor temperature, termed modified equation model with heat load input. In the approach with the first-order equation model, the collector inlet temperature term is treated as another parameter to be estimated as an effective collector inlet temperature. To evaluate the equation-based models, the Polysun simulation program is used for generating a data set of solar water heating system. For evaluation of daily solar collector yield estimation, two data sets were generated: training data set and testing data set. For evaluation of hourly solar collector yield estimation, training and testing performances were evaluated respectively. By using hourly simulated data, the hourly collector estimation performance was evaluated in terms of daily root-mean-squared error for the process of model training to compare the performance of fitness of the model for hourly estimation. The daily performance of two models showed quite similar estimation results. The comparison of the hourly performance of the two models resulted in a better performance of the modified equation model with heat load input.

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Keywords: Solar collector; Efficiency equation; Model prediction; Solar heat output

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Nomenclature

A_C	solar collector area
b_i	parameters used in modified efficiency equation where *i*=0,1,2,3 and 4
c_i	parameters used in first-order efficiency equation where *i*=0, 1 and 2
G_s	solar irradiance on solar collector
Q_s	solar heat output from solar collector
Q_L	heat load of solar heating system
RMSE	root-mean squared error
T_a	ambient temperature
T_{ci}	collector inlet fluid temperature
η_c	collector efficiency

1. Background

When predicting or calculating the solar yield of solar heating systems, system simulation can be used with subsystem models including solar collectors, solar storage tank, heat exchangers, and heating loads. The system model will include temperature-level physical system models to define each component in detail. It would be more convenient if the performance of each subsystem could be modelled at the energy level instead of detailed temperature level. Aiming at developing simpler prediction models for solar yield of solar collectors, the standard first-order collector efficiency equation has been modified to derive a modified efficiency equation [1] that replaces the collector inlet temperature term with a heating load term.

This study describes the performance of estimating or predicting the solar yield by using the equation-based model, termed modified equation model with heat load input, and compares its performance with another ad-hoc model using the standard first-order efficiency equation with constant collector inlet temperature.

2. Evaluation method

For prediction or estimation of solar yield based on simple efficiency equations, two equations are considered in this study:

- A modified collector efficiency equation with heat load input [1]

$$\eta_c = b_0 - b_1\left(\frac{1}{G_s}\right) + b_2\left(\frac{T_a}{G_s}\right) - b_3\left[\frac{\exp(-b_4 Q_L)}{G_s}\right] \tag{1}$$

where η_c=collector efficiency, b_0, b_1, b_2, b_3, b_4=parameters, T_a=ambient temperature, G_s=solar irradiance on solar collector, Q_L=heat load of solar heating system

- A first-order collector efficiency equation with constant $T_{c,i}$

$$\eta_c = c_0 - c_1\left(\frac{c_2 - T_a}{G_s}\right) \tag{2}$$

where c_0, c_1, c_2=parameters, T_a=ambient temperature, G_s=solar irradiance on solar collector. c_2 is the collector inlet temperature T_{ci} in the original first-order collector efficiency equation [2].

The heat output of solar collectors is calculated by using the collector efficiency.

$$Q_s = \eta_c G_s A_c \tag{3}$$

where Q_s=solar heat output from solar collector, G_s=solar irradiance on solar collector. A_C = solar collector area. The Polysun [3] simulation program was used to generate data sets for a solar water heating system. A solar domestic hot water system was considered with 4 ㎡ of collector area and 300 l of hot water tank. The daily hot water consumption was assumed to be 200 l and German BDH/BSW hot water usage profile was selected in this study. A flat-plate collector design was considered. The performance of estimating the solar yield using two equations is evaluated in terms of daily solar yield and hourly solar yield estimation. For performance evaluation of daily solar yield estimation, a 31-day period in August was selected for testing and 10 to 180 days of training period prior to August were considered for model training purposes. For performance evaluation of hourly solar yield estimation, the training performance of two models for one year was considered and the daily root-mean squared errors were compared.

3. Evaluation result

3.1. Daily performance

Figure 1 shows the root-mean squared error (RMSE) of training and testing processes of the modified equation-based model to evaluate daily solar heat output estimation. The two equations showed quite similar performance. The training period of 60 days from June to July prior to the testing period of 31days in August showed the best performance for both training and testing.

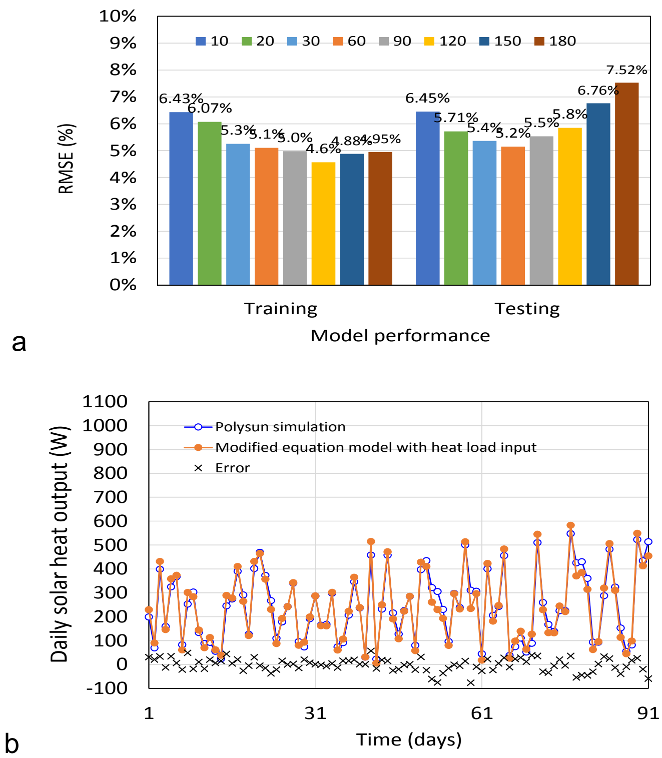

Fig. 1. Daily performance of the method (a) RMSE for training and testing and (b) solar heat output comparison with the Polysun simulation and equation-based model.

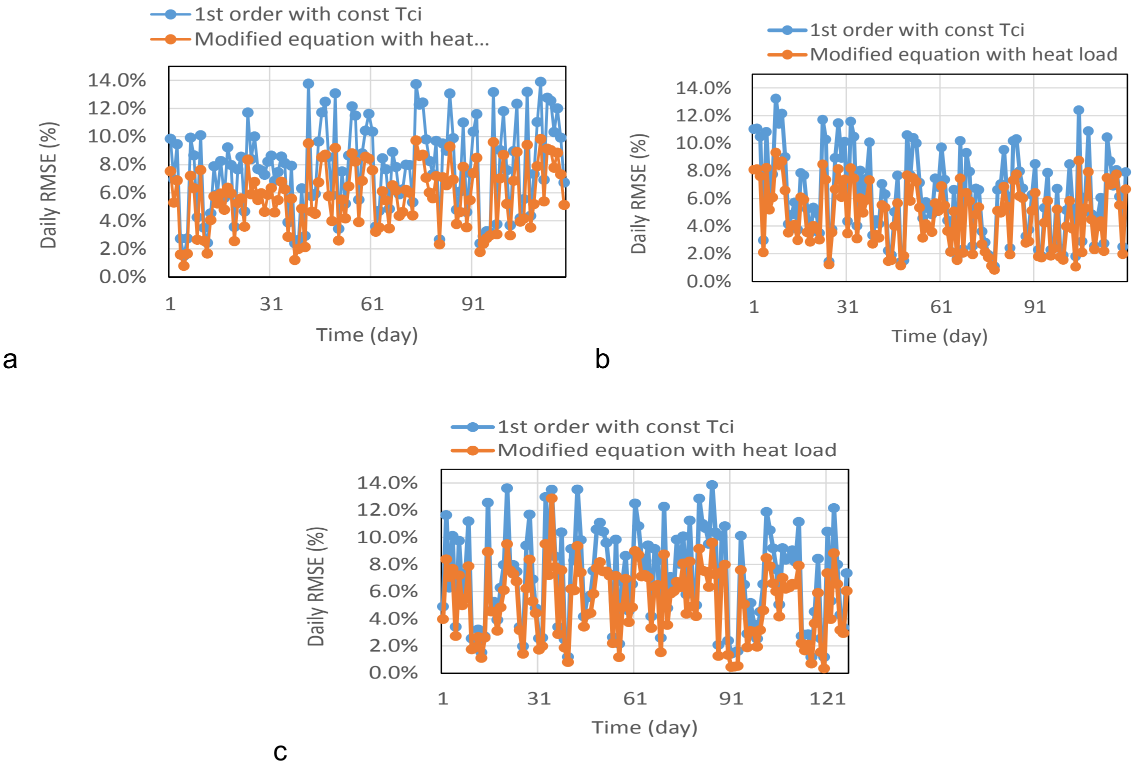

Fig. 2. Hourly performance expressed as daily RMSE for training performance of the models (a) January to April, (b) May to August, and (c) September to December.

3.2. Hourly performance

Figure 2 shows the training performance of two equation-based models by using hourly one year data. Errors were below 5% and 7% on average for the modified equation-based model and first-order equation-based model, respectively

The model prediction performance was tested for the modified equation-based model with different duration of the training data. Five training periods of 3, 7, 14, 21, 28 days were considered. The model prediction performance was evaluated for 7 days from February 1 to February 7. The data set used for training was for each period prior to the first testing day. For example, if we consider 3 days of training data set, the training period was from January 29 to January 31. Likewise if we consider 7 days of training, the training period was from January 25to January 31. All the model inputs such as ambient temperature, solar radiation on the collector, and heating load were assumed as predicted perfectly. Figure 3 compares the RMSE for different training periods. It is found that the testing performance of the model converges to a certain error level as the period of training days increases. It is also suggested that the period of training be longer than 7 days to obtain the converged testing performance in this case study. The average RMSE for the whole period of 7 days was about 3.7% in this case. Figure 4 shows the comparison of sample data for 7 days of testing when the training data set of 7 days was used.

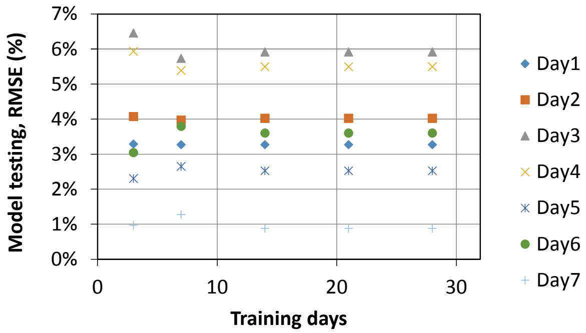

Fig. 3. Testing performance of modified equation-based model with different training period.

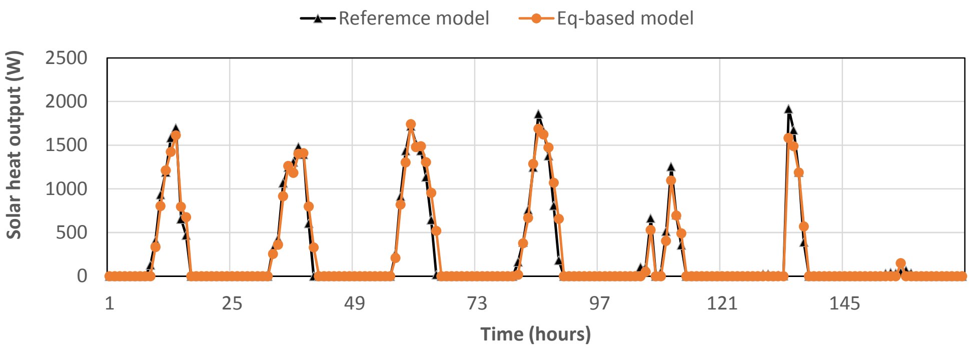

Fig. 4. Hourly solar heat output calculated from the reference model and modified equation-based model.

4. Conclusion

This study evaluates two equation-based models for solar collectors to estimate solar heat output daily and hourly, respectively. Two equations were used for the model-based method. One is a simple form of the first-order efficiency equation and the other is a modified efficiency equation that has a term of heating load instead of collector inlet temperature. The incident angle modifier was not considered for both equations. Training data sets were generated by using the Polysun software program for a solar domestic hot water system. Another different data set was generated by using the same system with the Polysun program for model testing. For daily prediction the two models showed quite similar performance. The modified equation-based model showed better performance for model training. For hourly testing of the modified equation-based model, different training data set periods were considered. It was found that the performance of hourly model prediction converges to a certain level as the training period increases and at least 7 days are suggested to obtain a converged performance in this case study.

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